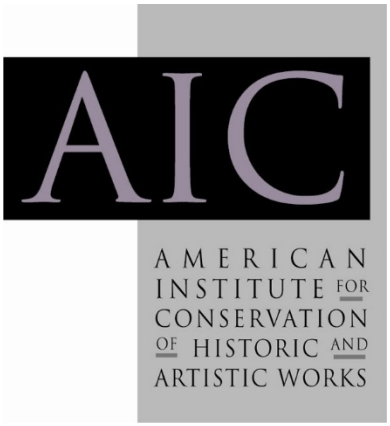




Article: Bringing history to life: Reproducing a Worthington steam pump from the USS *Monitor*
Author(s): William Hoffman
Source: *Objects Specialty Group Postprints, Volume Twenty, 2013*
Pages: 169-194
Editors: Lara Kaplan, Kari Dodson, and Emily Hamilton
ISSN (print version): 2169-379X
ISSN (online version): 2169-1290
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www.conservation-us.org

Objects Specialty Group Postprints is published annually by the Objects Specialty Group (OSG) of the American Institute for Conservation of Historic & Artistic Works (AIC). It is a conference proceedings volume consisting of papers presented in the OSG sessions at AIC Annual Meetings and is intended to inform and educate conservation-related disciplines. Under a licensing agreement, individual authors retain copyright to their work and extend publications rights to the AIC.

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BRINGING HISTORY TO LIFE: REPRODUCING A WORTHINGTON STEAM PUMP FROM THE USS *MONITOR*

WILLIAM HOFFMAN

ABSTRACT

On December 31, 1862, the USS *Monitor* sank off the coast of Cape Hatteras, North Carolina, taking to the ocean floor a complex mechanical steam system that included two direct-acting steam pumps built by Worthington and Baker of Brooklyn, New York.

In 1973, the *Monitor's* wreck site was discovered in 240 ft. of seawater, and in 1975 the site fell under the jurisdiction of the National Oceanic and Atmospheric Administration, which currently oversees, protects, and studies the wreck. Over the past three decades, the National Oceanic and Atmospheric Administration, with the assistance of the US Navy, has recovered over 200 tons of material from the site, including the two Worthington pumps in 2001.

Since 1987, when it was designated as the repository of all *Monitor* artifacts, The Mariners' Museum in Newport News, Virginia, has been conducting conservation treatment on recovered objects to stabilize and preserve them for eventual display and curation. As deconcretion and conservation treatment began on the Worthington pumps, much of the artifacts' original surfaces were exposed. This not only enabled the advancement of the treatment process, but also revealed machining, file, and casting marks left on the objects from the manufacturing process. Also, through the use of x-radiography, loss due to years of corrosion as well as structural weakness to some of the surviving components soon became apparent.

As the conservation treatment of the pumps progressed, discussion of final display also began, which led to further dialogue on how to visually convey to the public the pumps' movement. By conservation ethical standards and from structural loss and weakness, operation of either original pump is not possible, so the use of a 3D model was suggested. However, it was felt that a computer-generated model could never fully represent the impact of a live-running steam pump. Therefore, in 2010, Mariners' Museum conservators began a project to create an operational replica of the pumps using multiple molding methods, laser scanning, computer-aided drafting, fused deposition modeling, and several casting and machining techniques.

This article provides an overview of the methods and challenges of reproducing a variety of pump components using both modern and traditional casting methods aided by the interpretation of foundry marks that remained on original components. Furthermore, it will describe the outreach potential of a project of this scale and how it has been used to attract new audiences, gain donor support, and spread awareness about the need for conservation.

1. BACKGROUND

On the night of December 30, 1862, the USS *Monitor* was caught in a storm 16 mi. off the coast of Cape Hatteras, North Carolina, and sank beneath the waves in the early morning of December 31, taking to the ocean floor a complex mechanical steam system created by the ironclad's designer, engineer Captain John Ericsson. This included a large "vibrating" side-lever trunked engine to drive the ship's propeller, two engines to drive centrifugal fans, two engines to rotate the massive gun turret, a large centrifugal steam pump, and two direct-acting steam pumps designed by Henry Rossiter Worthington and built by Worthington and Baker of Brooklyn, New York (fig.1).[1]

In 1973, *Monitor* was discovered laying upside down on the seafloor at a depth of 240 ft. by a team consisting of members from Duke University, Massachusetts Institute of Technology, University of Delaware, and the North Carolina Department of Natural Resources. The wreck site was confirmed to be *Monitor* in 1974, and in 1975 the site fell under the jurisdiction of National Oceanic and Atmospheric Administration (NOAA) with the establishment of the *Monitor* National Marine Sanctuary (Broadwater 2012).

Starting in the late 1990s, archaeologists from NOAA with the assistance of the US Navy's Mobile Diving Salvage Unit II began a large-scale recovery of the aft portion of the wreck after determining the ship was in an advanced state of deterioration.

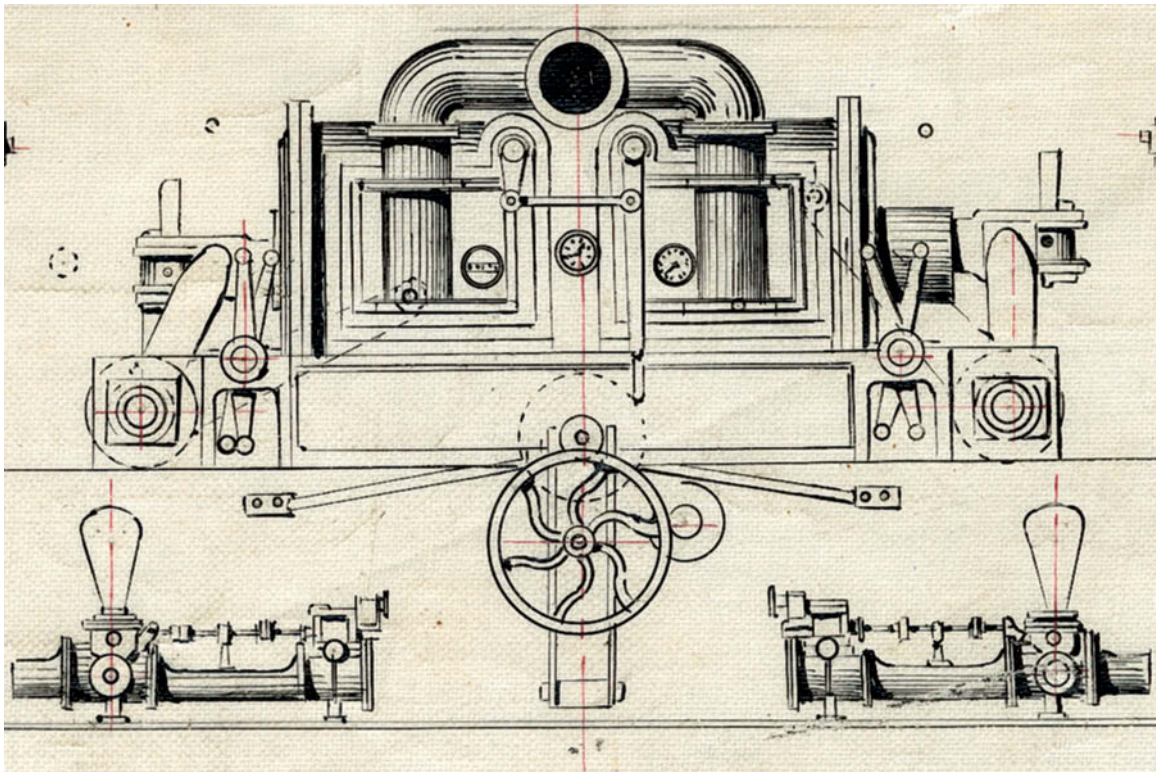


Fig. 1. Detail view of the main engine and Worthington pumps from the "General Plan" of *Monitor,* drawn by The Continental Iron Works (Courtesy of The Mariners' Museum)

The goal of the recovery was to retrieve *Monitor*'s most significant components and artifacts culminating in the raising of the ironclad's iconic 120-ton revolving gun turret, which had become pinned underneath the engine room of the ship (Broadwater 2012). Before the turret could be raised, NOAA and the Navy had to remove the ship's 20-ton main steam engine along with much of the engine room itself in 2001. The fully exposed turret was recovered in 2002 leading to a total recovery of approximately 200 tons of material.

Artifacts removed from the wreck site were destined for The Mariners' Museum in Newport News, Virginia, which was designated as the principle repository for the management and curation of *Monitor* related materials in 1987.

2. *MONITOR*'S WORTHINGTON PUMPS

Both of the *Monitor's* Worthington steam pumps were recovered during salvage efforts in 2001 and are believed to be the oldest surviving examples of this type of pump in the world. Ericsson placed the pumps on the ironclad for removing bilge water, for firefighting, pumping feed water, and other general uses (Hanley et al. 2009). They are thought to be "off-the-shelf" items and were purchased to be installed on the ironclad rather than specifically designed for the ship. The style of pump was advantageous for marine applications because it functioned independently of the main engine and was compact in size and light weight in comparison to contemporary flywheel and beam pumps of the time (Hanley et al. 2009).

When the pumps arrived at the museum, little was known about how they operated or what their physical condition was like underneath the concretion of sediment, corrosion products, and marine life as seen in figure 2. Therefore, x-radiography was carried out on the port pump, which revealed the internal



Fig. 2. Starboard Worthington pump before treatment, encased within concretion, *Monitor* Collection, MNMS.2001.03.039 (Courtesy of The Mariners' Museum)

arrangement of its mechanical features and identified much structural loss due to corrosion (fig. 3). For example, much of the pump's cast iron components had suffered from graphitization, a galvanic corrosion process through which the iron constituent of the alloy corrodes away leaving behind a fragile carbon-rich matrix as seen with the dampening piston cover in figure 4 (Cronyn 1990). Although the components looked structurally stable, the graphitized areas had the physical strength of hard chalk and could be easily fractured. The amount of corrosion-related loss varied widely with some components almost completely de-alloyed while others were nearly entirely intact.

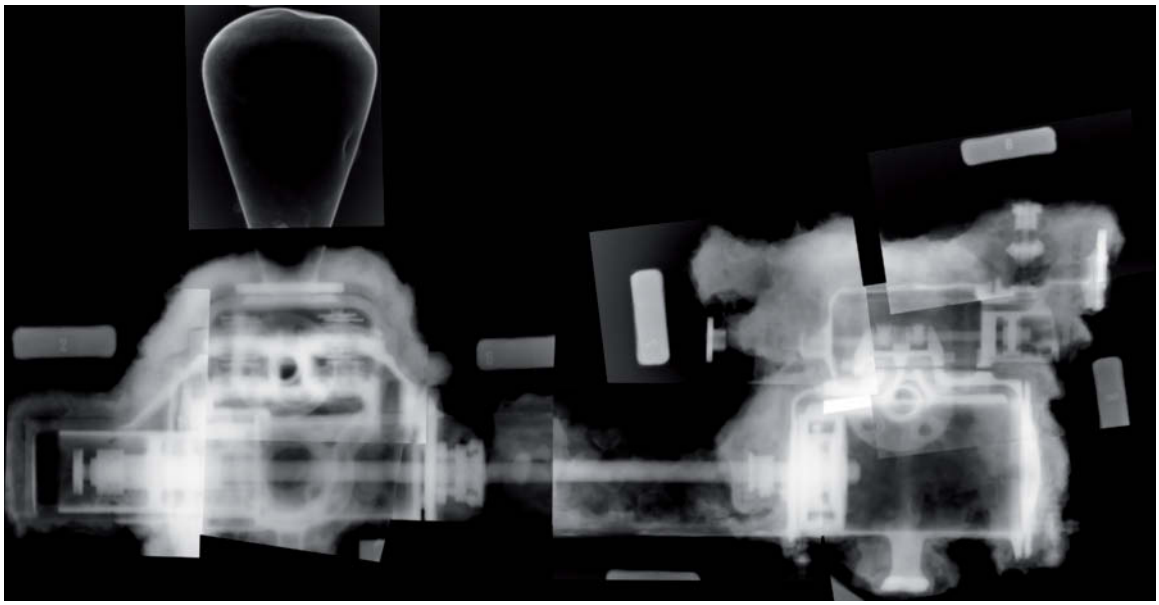


Fig. 3. Composite x-rays of port Worthington pump before treatment, *Monitor* Collection, MNMS.2001.03.037 (Courtesy of The Mariners' Museum)

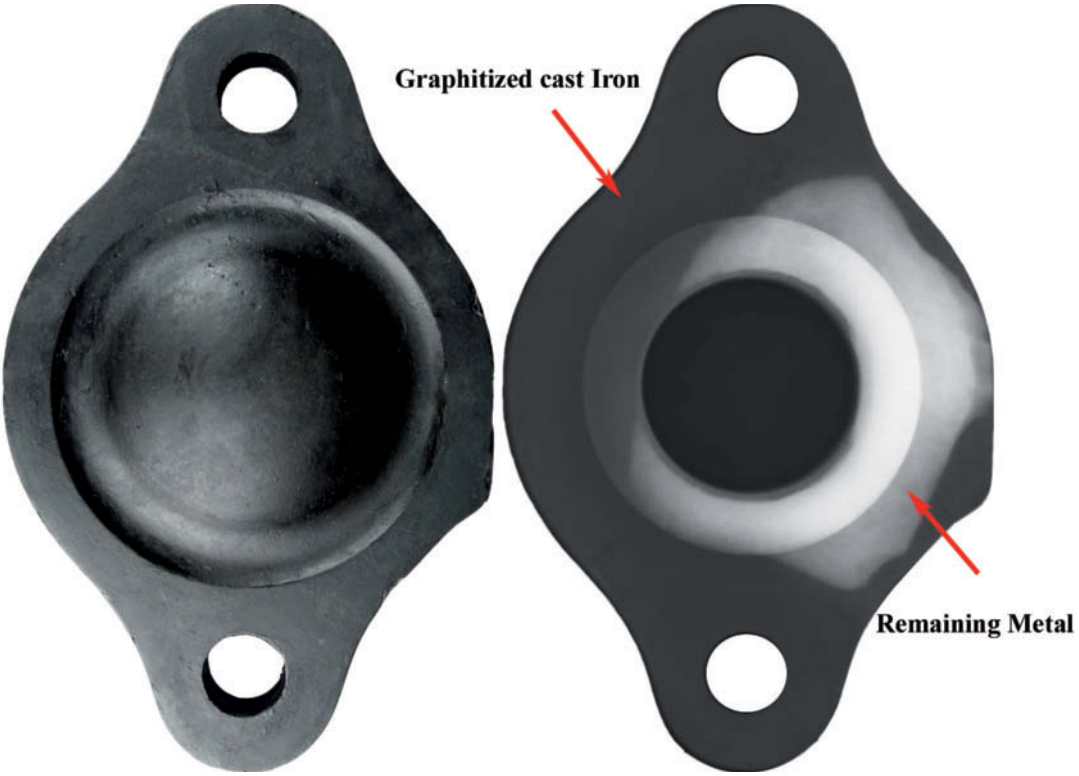


Fig. 4. Composite image of the port pump's dampening piston cover showing the treated object on the left and its x-ray on the right, revealing the extent of graphitization of the artifact, *Monitor* Collection, MNMS.2001.03.037D08 (Courtesy of The Mariners' Museum)

2.1 CONSERVATION TREATMENT

Physical treatment of the pumps has involved careful mechanical cleaning using a variety of hand and pneumatic tools to remove the thick layers of concreted material from their surfaces as seen in figure 5. This was followed by placement into sodium hydroxide or sodium sesquicarbonate solutions in conjunction with electrolysis to extract chlorides and further remove concretion and corrosion



Fig. 5. Starboard Worthington pump undergoing deconcretion, *Monitor* Collection, MNMS.2001.03.039 (Courtesy of The Mariners' Museum)

products. Contemporaneously with chemical treatment, the pumps were carefully disassembled so that subcomponents could be independently treated. Not all component assemblies could be safely dismantled due to structural fragility and were left together.

Once the pump elements were desalinated, they were carefully dried using both solvent replacement and controlled air-drying. Final treatment, which is still in progress for many components, has involved the application of tannic acid (for iron components) or benzotriazole (for copper alloys) followed by structural consolidation and surface coating using several acrylic resins.

2.2 METHODS OF MANUFACTURE

As conservation progressed and the surfaces of the pumps' assemblies were exposed and cleaned, they were revealed to have a high quality of manufacturing and machining skill with precision cut threading, perfectly planed surfaces, and seamlessly mating parts. Additionally, for the components that were not completely machined, in many cases, their method of casting could be determined by marks left on the objects from the foundry process such as their overall surface textures, filing marks, and the remains of the pour systems used to supply liquid metal into the mold cavities to produce the castings.

One component that clearly showed identifying marks was the steam cylinder and central cradle from the starboard pump (fig. 6). Upon close inspection of the artifact, its rough surface texture indicated that it was produced using a sand casting molding method. This was further supported by the presence of a mold parting line running down the center of the object in conjunction with a filed down curved flashing line. Flashing often occurs where several parts of a mold join together and is a thin line of excess metal that had partially run into the seam between mold sections. It was usually filed down during the

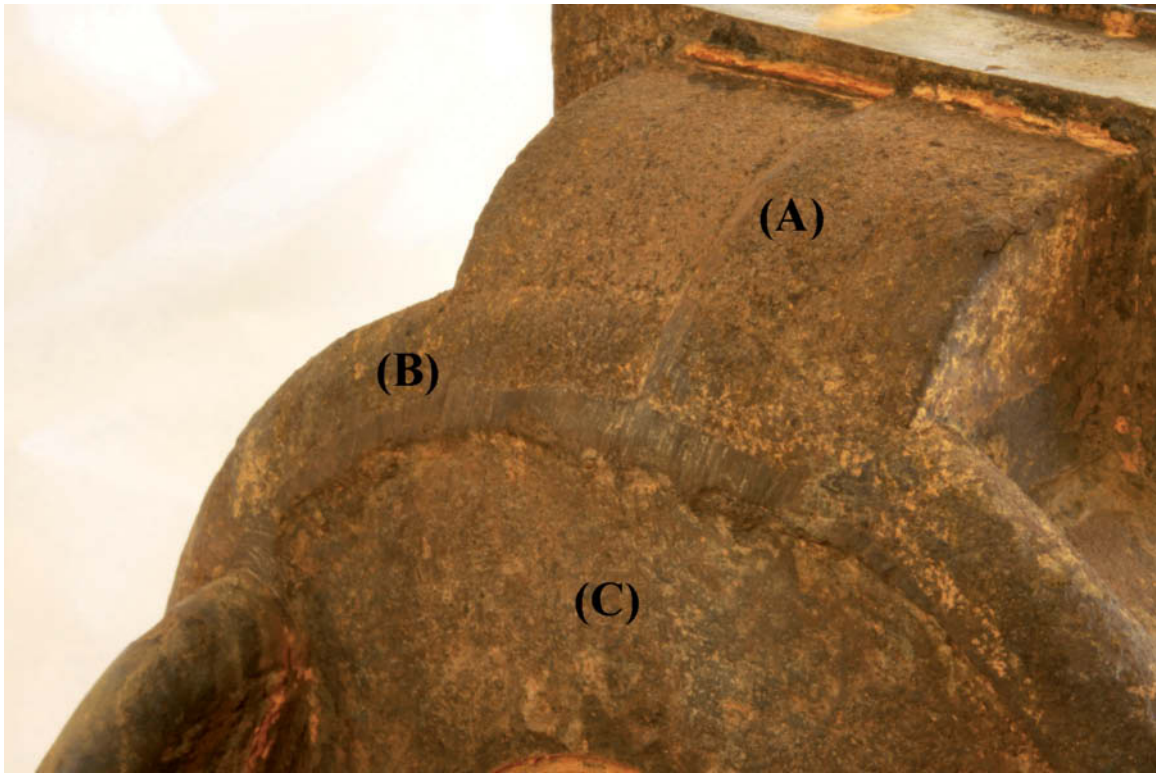


Fig. 6. Detail view of the inner top surface of the starboard pump post-drying with (A) indicating the location of the mold parting line, (B) showing the curved flashing line, and (C) identifying the absence of a parting line (Courtesy of The Mariners' Museum)

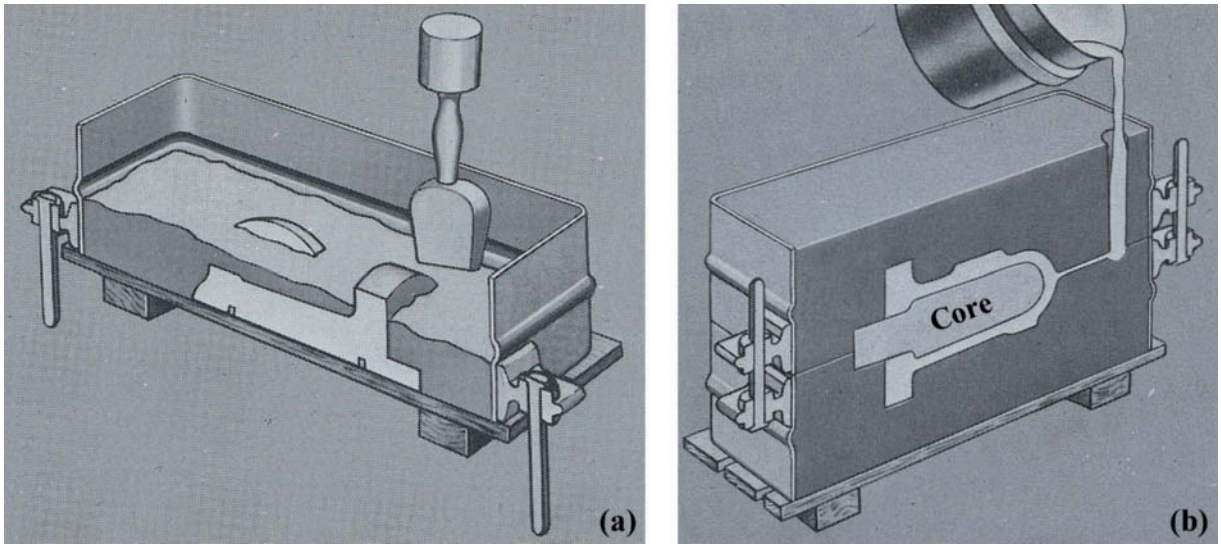


Fig. 7a. Green sand being compressed around a wooden pattern set in a metal flask; 7b. Liquid metal being poured into a completed mold with core suspended in the middle (Diagrams adapted from Walton 1971)

finishing stage of the casting process. Note that the parting line does not extend past the flashing line, which indicates the use of a core mold. Furthermore, multiple passageways can be seen running through the interior of the object and could have only been produced through the use of core molds.

2.2.1 Green Sand Molding Method

From these observations, the production method for the cylinder and cradle was determined to be green sand molding. This process involved taking the mold of a wooden pattern by compressing a water-bound mixture of sand and clay around it within a flask (box) using a variety of hand tools (fig. 7). The term "green" indicated the presence of moisture within the molding sand and identifies it as not being dried or baked (Walton 1971). Molds were produced in at least two halves, which enabled the removal of the pattern from the final mold creating a cavity for metal to enter. Casting patterns were also often made in multiple pieces to ease their extraction from the molding medium. Additionally, to produce a hollow casting, a core mold was inserted into the mold cavity. Unlike the green sand used to create the outer mold, core sand was mixed with a binder such as linseed oil and then baked in an oven to harden it so it was self-supporting. To fill the mold, liquid metal was poured down into the mold through a vertical passageway called a sprue into a horizontal channel called a runner, which was connected to the mold cavity enabling the metal to fill it and produce the casting.

3. SHARING THE PUMPS' STORY WITH THE PUBLIC

As treatment of the Worthington pumps moved forward, discussion began on how best to display them in the museum's galleries once conservation had been completed. Due to their fragility, operation of the pumps would not be possible, and even if they could function, physical wear to the components through the process would go against conservation ethics. Therefore, the question arose of how to best relay to the public the grandeur of live running steam pumps when the pumps would be displayed statically in cases. The first thought was to use a computer-generated model to show the pumps in operation, possibly on an adjacent interactive flat screen. However, it was still felt that this could not convey the full excitement of

an actively running pump. The discussion was then turned to the question of whether a working replica could be made by interpreting the casting information from the pumps, reverse engineering them, and replicating a new pump using similar casting methods.

The project had collaboration written all over it. An endeavor of this scale could not be carried out by The Mariners' Museum alone and would create a perfect opportunity to partner with other nonprofit organizations, government institutions, private industries, and academic institutions. Furthermore, reproducing the pump would enable the conservation staff to better understand how the original parts were manufactured. It would also allow for consultation and discussion with experts in a variety of technical fields who through the replication process could share valuable expertise and knowledge, which could help to provide insight into 19th-century steam engine and casting technology. Importantly, the completed pump would be a perfect pathway for public outreach. Not only could it be used within the museum as an educational tool to help teach about steam and casting technology, but it could be taken on the road to help share the ironclad's story to the broader public. Lastly, the project could be used to show the importance of conservation by highlighting the fragility of the original pumps while at the same time illustrating the amount of information that can be gathered though the treatment process.

4. REPLICATION PROJECT

The replication project was begun in the fall of 2010 by copying and casting the valve chest and dampening piston covers for proof-of-concept, video recording the process for later interpretation. The test castings proved quite successful and over the course of the next three years, 42 components were replicated in cast iron or bronze. All artifact molding and pattern preparation work was carried out at The Mariners' Museum. Conservators then made six trips to the State University of New York College at Buffalo having partnered with its sculpture studio to utilize the facility's iron and bronze foundries for sand mold work and metal casting. By partnering with the studio, the museum was able to minimize the cost of foundry work while at the same time providing sculpture students with an opportunity to learn about traditional casting and molding methods. Final machining work of the parts cast by hand along with additional parts milled straight from solid metal stock (still in progress for some components) has been carried out by Master Machine and Tool Co. Inc. of Newport News, Virginia, which partnered on the project in 2012 and has provided invaluable support and technical expertise without which the project would not be possible. Additionally, major funding to launch the replication and machining of components came from a $40,000 donation received from the Curtiss-Wright Flow Control Company's Engineered Pump Division, which had acquired the remaining form of the original Worthington Pump Company in the early 2000s. Curtiss-Wright employees were eager to help in whatever way they could and saw the project not only as an opportunity to provide outreach, but also as a means of supporting the long, rich heritage of the Worthington pump and its role on USS *Monitor*.

4.1 SOLID COMPONENTS

The method developed for the replication of non-cored solid components followed a three-stage molding process, which resulted in the creation of three copies of each original artifact starting with the first in plaster, the second in plastic, and the final in cast metal.

4.1.1 First Molding Phase: Alginate

The molding process began with direct-mold work off the original pump components using dental alginate impression material as seen in figure 8 with the copying of the slide valve. Due to the fact that many of the components were fragile and undergoing wet treatment, alginate molds were taken prior

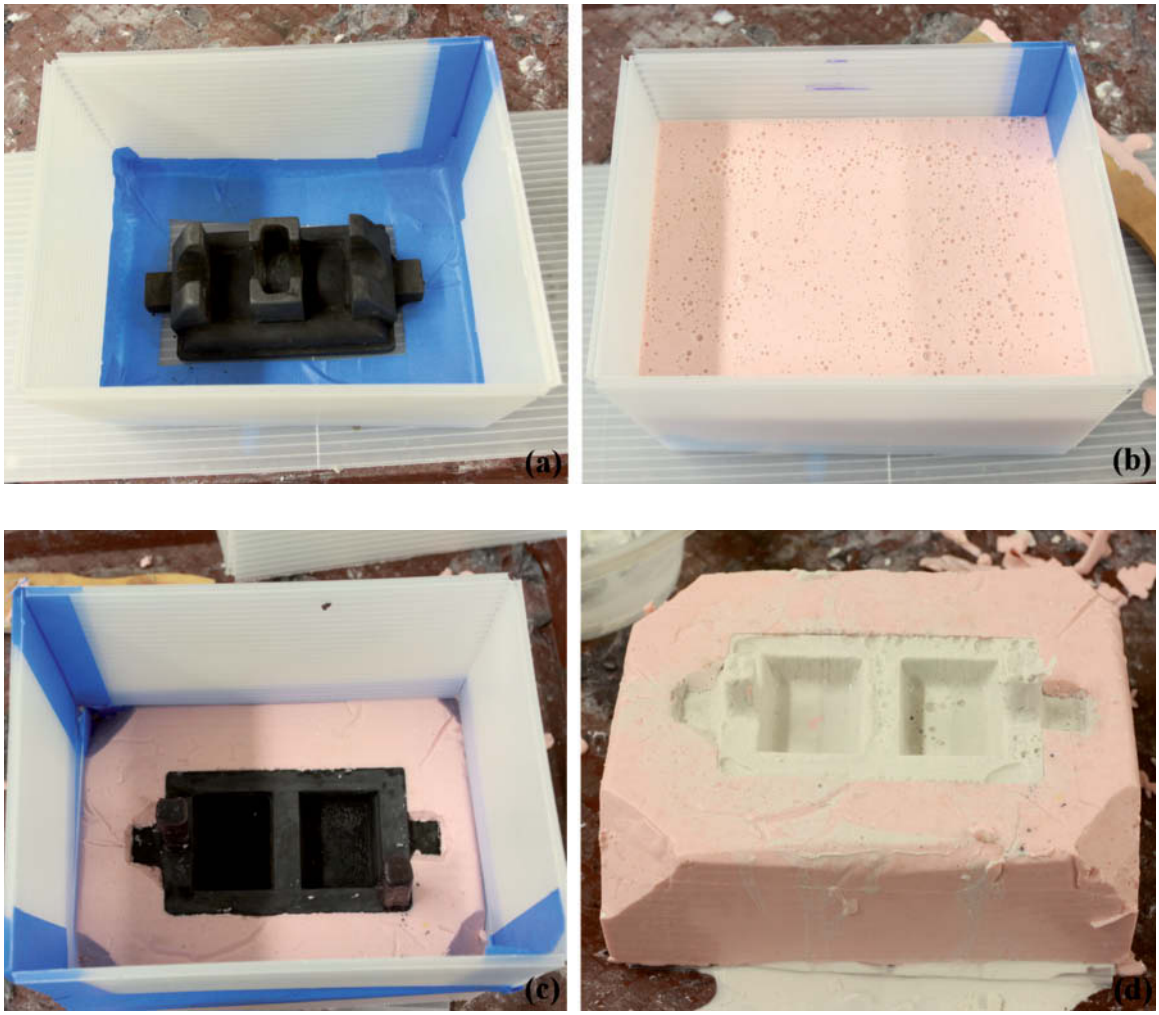


Fig. 8a. Slide valve (MNMS.2001.03.037D13) set in flask to be molded; 8b. Alginate compound poured over object and allowed to cure; 8c. Mold turned over and prepared to receive additional alginate; 8d. Plaster cast made of the valve still embedded in the molding medium (Courtesy of The Mariners' Museum)

to drying and post-desalination. Alginate is an aqueous rapidly setting organic molding material used in dentistry to make accurate teeth and gum impressions and solidifies against wet surfaces. It proved advantageous for this project because a release agent was not required with water itself acting as a barrier layer keeping the molding material from sticking to the surfaces of the components. Also, if any of the material remained on an object post-demolding, when the component was dried, the alginate dried out as well and could be brushed away during final mechanical cleaning.

Most molds were constructed in two sections and upon curing of the molding material, the halves were separated and the artifacts removed. The molds were reassembled and plaster poured in. As soon as the plaster had solidified, the molds were removed and the new casts were allowed to dry. Post-drying, the plaster copies received additional modification and cleaning with imperfections sanded off and losses filled in with Roma Plastilina clay.

4.1.2 Second Molding Phase: Rubber

The plaster casts then underwent a second molding phase to create two-part rubber molds. Brush-on 35, a brushable two-part urethane rubber by Smooth-on Inc., was selected due to its ease of

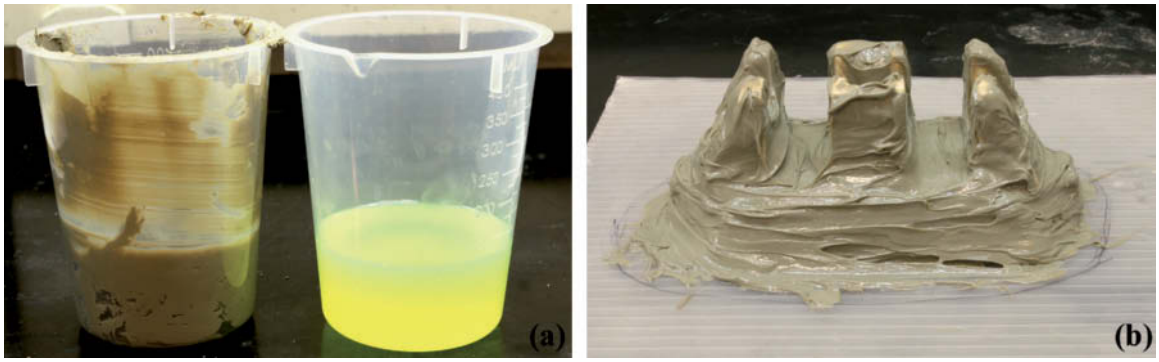


Fig. 9a. Rubber components prior to mixing; 9b. Rubber being applied to the plaster cast (Courtesy of The Mariners' Museum)

application and strength and flexibility upon curing (fig. 9). After the rubber was applied to the casts, they were encased in plaster, which acted as a support structure for the rubber when the molds were disassembled and the casts removed.

As with the first phase, most molds were created in two sections and on completion, the molds were carefully worked apart and the plaster casts removed (fig. 10). The mold halves were brought back together and clamped tightly (fig. 11). The empty mold cavities were filled with Smooth-cast 310, a two-part liquid casting plastic also by Smooth-on Inc., which when cured created new casting patterns for the pump parts in a hard white sandable plastic (fig. 12).

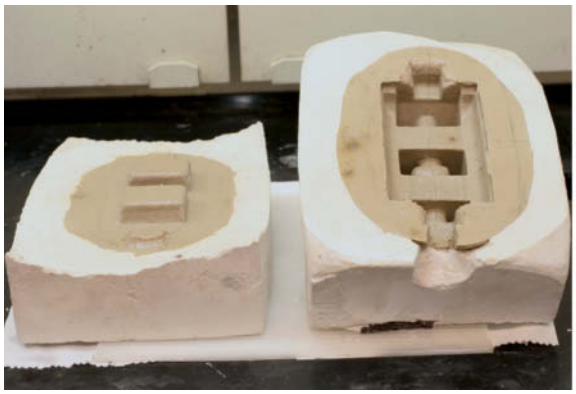


Fig. 10. Plaster cast removed from two-part mold (Courtesy of The Mariners' Museum)

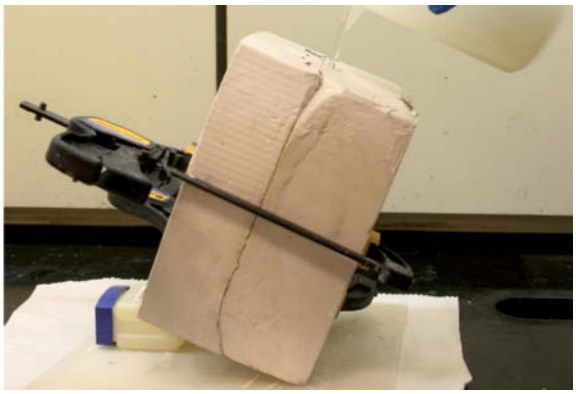


Fig. 11. Mold sections clamped and plastic poured in (Courtesy of The Mariners' Museum)

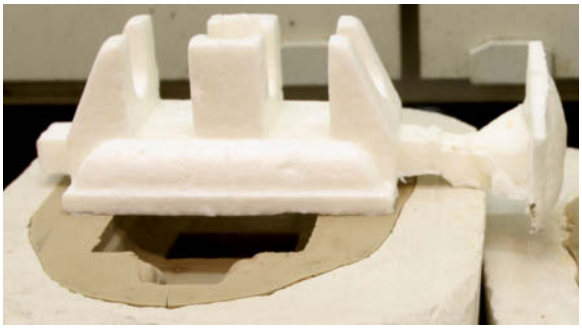


Fig. 12. Plastic copy of slide valve after removal from rubber mold (Courtesy of The Mariners' Museum)



Fig. 13. Multiple plastic copies of the dampening piston cover mounted in a wooden flask (Courtesy of The Mariners' Museum)

4.1.3 Third Molding Phase: Resin-Bonded Sand

During this stage, the plastic patterns were placed into wooden flasks as can be seen in figure 13 with plastic copies of the dampening piston cover.[2] Fine sand and a urethane resin with catalyst were mixed together in a large motor driven muller and then poured over the objects. Using the same technique as in the green sand molding method, wooden tools were utilized to compress the sand against the patterns and the walls of the flasks (fig.14).

Once the flasks had been filled, the resin was allowed to harden for 24 hours bonding the sand together. After the resin cured, the flasks were removed from the now hardened blocks of sand. The mold

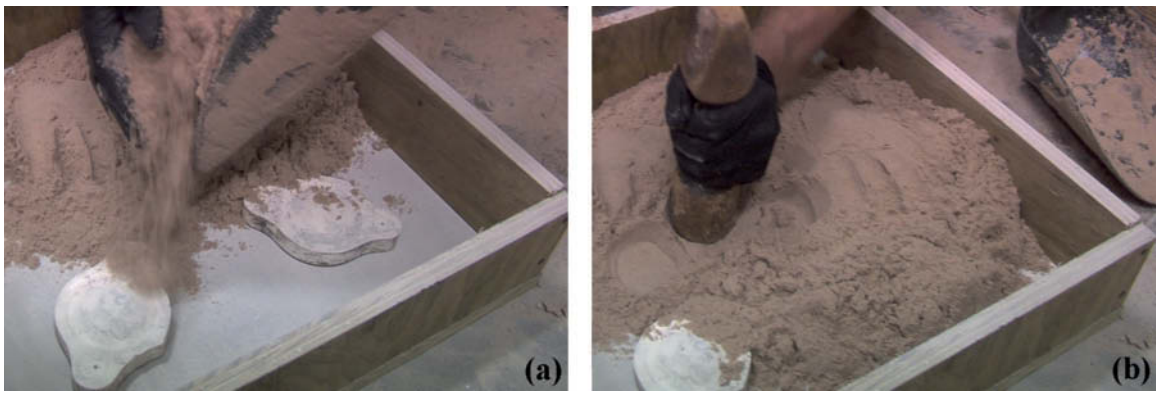


Fig. 14a. Resin-saturated sand being poured into mold; 14b. Wooden bench rammer compacting sand against the surfaces of the pattern and walls of the flask (Courtesy of The Mariners' Museum)



Fig. 15. Dampening piston cover copies half-embedded in a hardened block of sand with attached flask awaiting additional sand to be added (Courtesy of The Mariners' Museum)

halves were turned over exposing the remaining sides of the patterns. After some brief cleaning of the exposed surfaces, the flasks were reattached around the sand blocks a third of the way up to create cavities that would become the second halves of the molds (fig. 15). More resin-saturated sand was prepared, and the cavities were filled using the same method as with the first side.

The completed mold sections were carefully separated using wedges and light pressure exposing the patterns, which were removed. Pour systems were then added using a drill and grinding stone with runners and reservoirs cut into what would be the lower sand blocks and vent holes and sprues drilled into the upper blocks (fig. 16). These passages would become the pathways for liquid



Fig. 16a. Runners cut into sand block connecting the four mold cavities to a central reservoir; 16b. Main sprue passage located at the center of the mold section to meet up with the reservoir and four small holes drilled into each upper mold cavity for venting air and other gasses (Courtesy of The Mariners' Museum)



Fig. 17a. Banding being fitted around mold halves; 17b. Sand cup attached to top of completed mold (Courtesy of The Mariners' Museum)



Fig. 18a. Metal shears being used to cut through the steel banding; 18b. Exposed castings still embedded within mold half (Courtesy of The Mariners' Museum)

metal to enter the mold cavities, while at the same time allow air to escape. After the casting channels were added, the two sides of the molds were fixed together with a special adhesive, and then steel banding was used to firmly hold the halves together (fig. 17a). Hardened sand cups were adhered to the molds and became the entryway for either liquid iron or bronze to be poured in depending on what part was being replicated (fig. 17b). Once the metal had solidified, the banding was cut and the mold halves separated exposing the new castings, which would then receive final finishing at the machine shop (figs. 18a, 18b).

4.2 CORED COMPONENTS

Although replication of the solid components was by no means easy, the real challenge came with the reproduction of the pumps' major assemblies such as the steam engine and cradle (fig. 19). The sheer size of the artifact made direct-molding highly impractical and the process could not copy the intricate



Fig. 19. Starboard pump steam engine and cradle during treatment prior to drying, *Monitor* Collection, MNMS.2001.03.039B (Courtesy of The Mariners' Museum)

passageways that ran through its interior. Therefore, a different procedure was developed to recreate the components, which led to the blending of modern and traditional technology.

4.2.1 Laser Scanning

To create a casting pattern of the steam engine and cradle, the artifact was laser scanned using a Leica T-Scan coupled with a Leica absolute laser tracker (fig. 20). The T-scan is a handheld laser scanner that records the surface topography of an object through a triangulation system in which a camera mounted within the scanner tracks a laser beam as it travels across an object's surface. Due to the T-scan being free-floating, a reference point is required to ground the data being recorded in three-dimensional

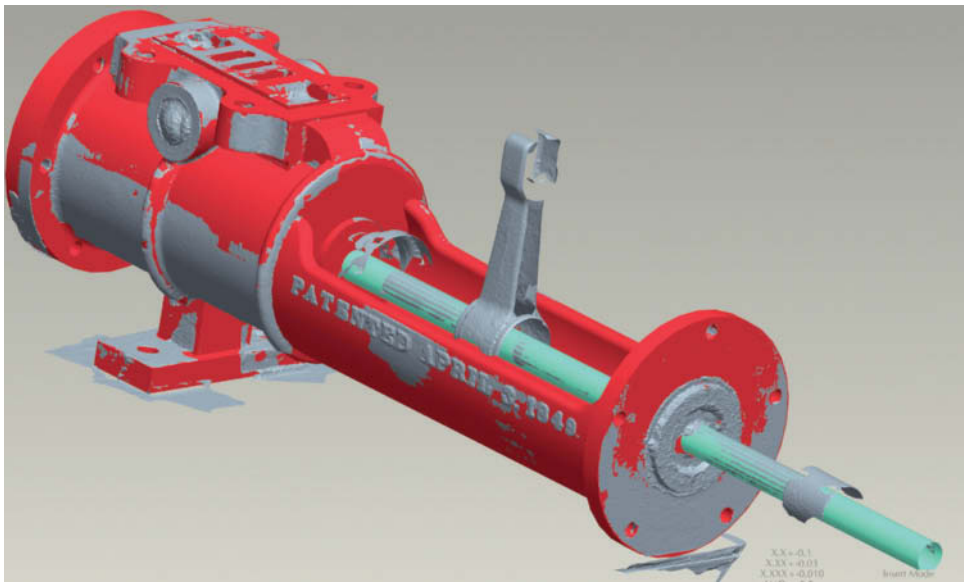


Fig. 20. Laser-scanned image of the starboard pump's steam engine and cradle (Courtesy of The Mariners' Museum)

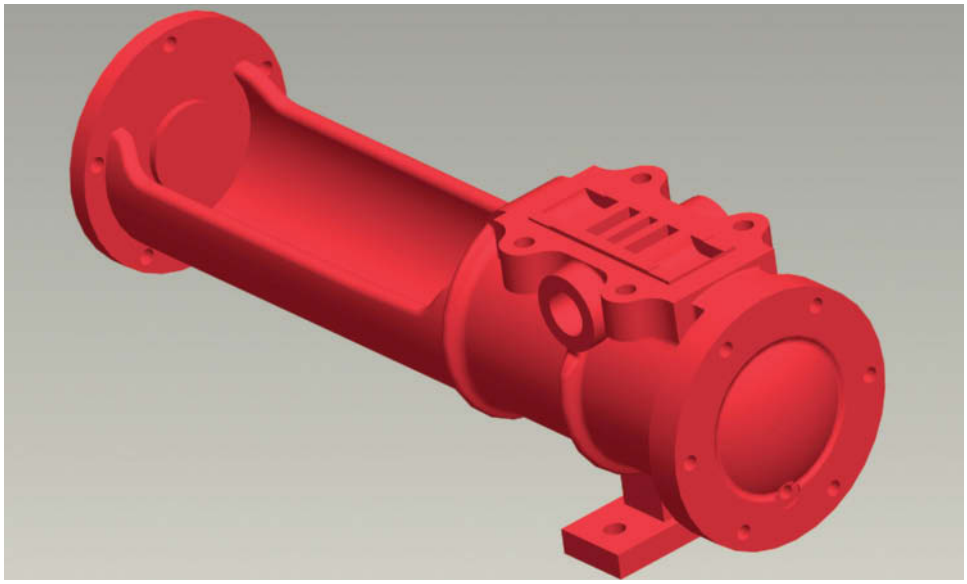


Fig. 21. Computer model of the steam engine and cradle (Courtesy of The Mariners' Museum)

(3D) space. Therefore, a second fixed-location laser scanner is used to identify the location of the object being scanned in reference to it and to track the position of the handheld device as it is moved around the object.

4.2.2 Computer-Aided Drafting Modeling

After the artifact was scanned, the data was transferred into a computer-aided drafting (CAD) program through which losses were filled using computer software creating an accurate 3D model of the engine (fig. 21). The CAD model was then digitally cut apart and the interior steam passageways where rendered guided by visual study of x-rays of the artifact in comparison with physical measurements taken using calipers as references (fig. 22).

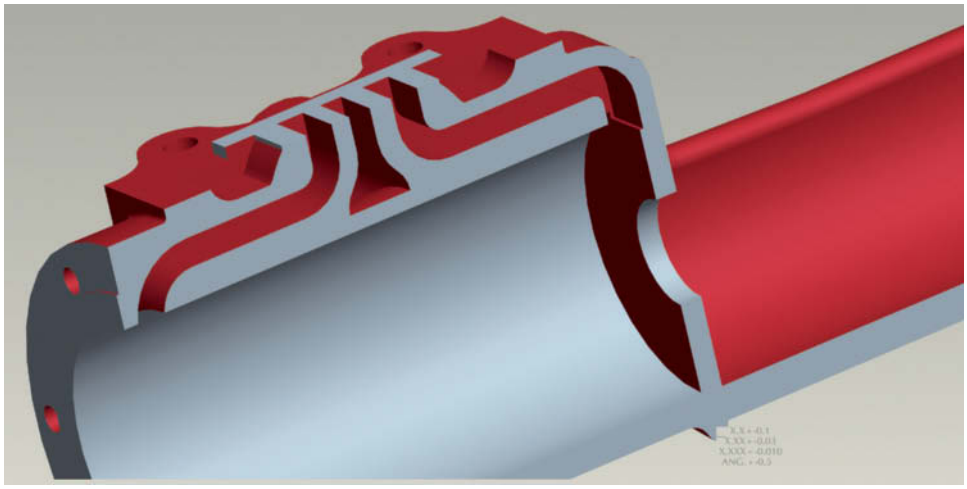


Fig. 22. Cut way view of engine piston cylinder showing rendered interior steam passageways (Courtesy of The Mariners' Museum)

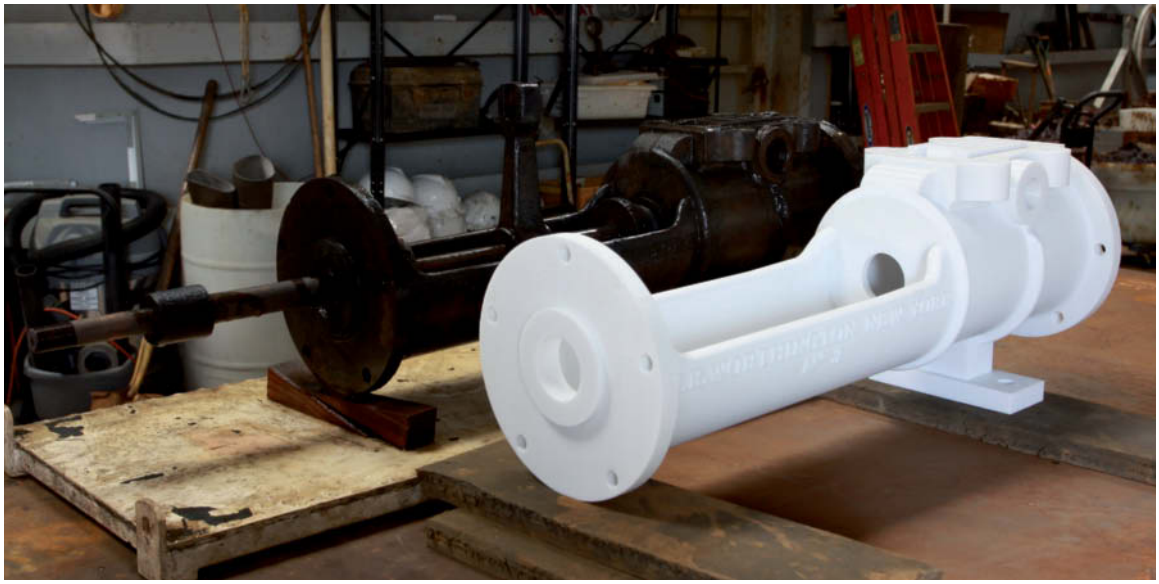


Fig. 23. View of plastic print next to original artifact (Courtesy of The Mariners' Museum)

4.2.3 Fused-Depositional-Modeling

The modified data was imported to a Stratasys brand Fortus 900mc 3D printer, which produced a polycarbonate plastic copy of the object in four pieces using Fused-Deposition-Modeling (FDM). FDM technology builds an object layer-by-layer by heating a thermoplastic material to a semi-liquid state and then extruding it according to a computer-controlled pathway (Stratasys Ltd. 2013). The newly printed sections were fixed to each other with steel pins, creating an accurate copy of the steam engine and cradle (fig. 23). These would become the casting pattern to reproduce the artifact in iron. Prior to work at the foundry, the surfaces of the 3D print were coated with a thin layer of Roma Plastilina clay to mask the lined surface texture on the object from the printing process. Bolt holes were also filled in with clay so that they would not inhibit the molding process by creating undercuts on the casting pattern.

4.2.4 Planning the Casting

Once the new pattern was completed, a molding plan was devised in order to be able to make a sand mold off it and to develop a pouring system that would enable metal to flow into the final mold properly to produce a good casting (fig. 24). A complex component like the steam engine and cradle required a multiple-piece mold that had to be constructed in a certain sequence in order to be able to take it apart, remove the pattern, and put it back together again. This was one of the more challenging stages of the project, because a mistake made in mold construction could lead to a failed casting attempt. As planning was conducted, the original artifact was referenced and its casting marks used as a map to guide how the new mold would be made. From the observations, a seven-piece mold was required consisting of two side pieces, one end piece, a top and bottom piece, and two core components. The best option for feeding metal into the completed mold was to run a sprue down through one side section and connect it to a trough built into the bottom portion of the mold.

The general concept being that liquid iron would fill the mold cavity from the bottom up while pushing air out through venting passageways in the top mold section.

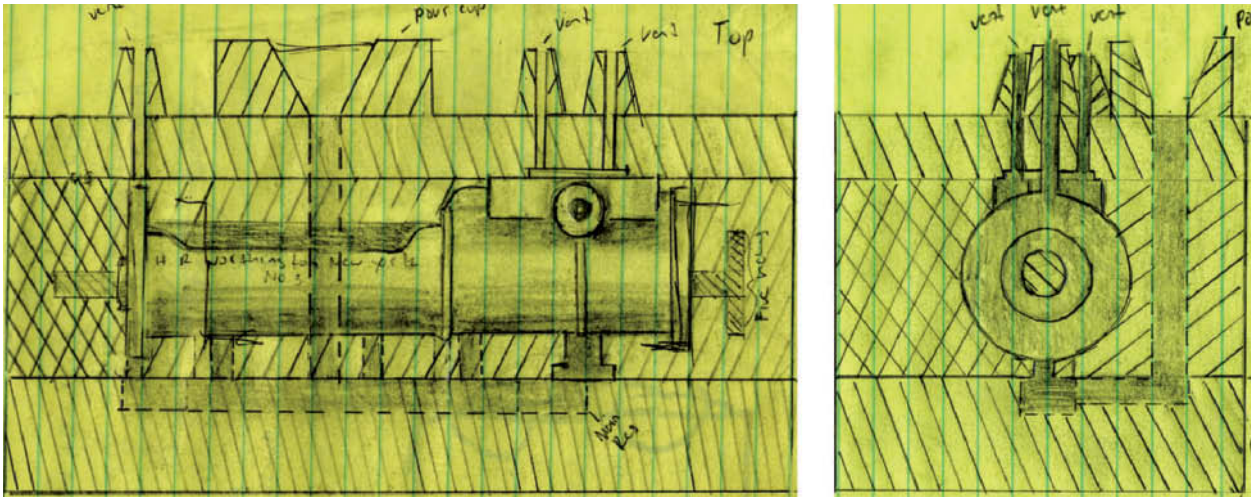


Fig. 24. Mold plan outlining pour system and mold assembly (Courtesy of The Mariners' Museum)

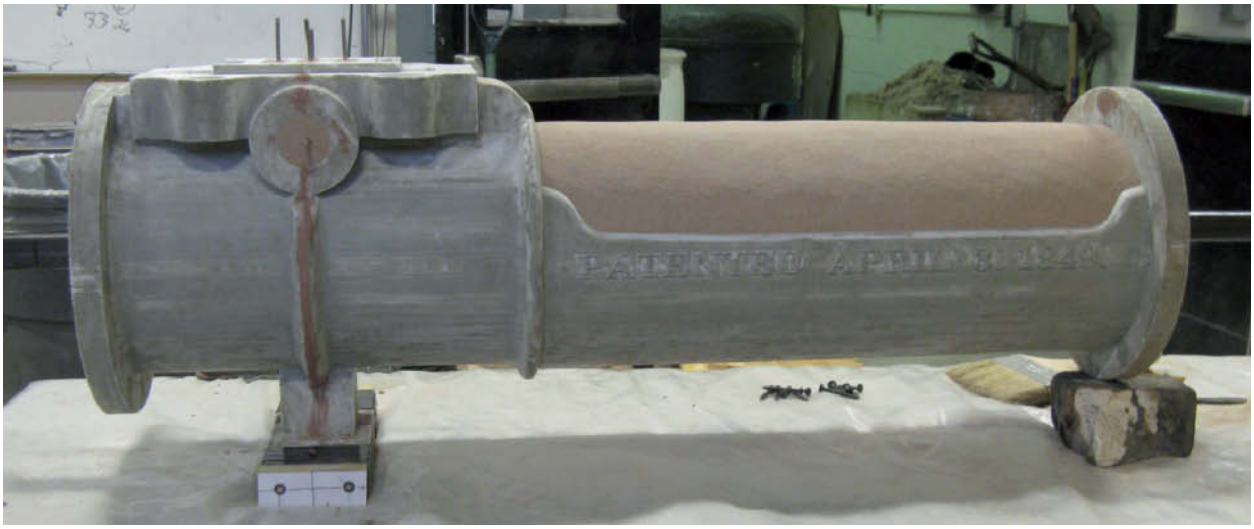


Fig. 25. View of the clay-skinned print showing resin-bonded sand packed into its interior cavities (Courtesy of The Mariner's Museum)

4.2.5 Resin-Bonded Sand Mold

With a completed molding plan, the pattern was taken to the foundry where the mold was constructed around the object beginning the packing of resin-bonded sand on the interior of the pattern to make the mold cores (fig. 25).

Once the core sand had chemically set (approximately 24 hours), the pattern was turned on its side, placed in a wooden flask, and divided into two sections creating a seam-line running down the middle of the object (fig. 26). The sides were then filled with resin-bonded sand, with the second side being completed when the first side had cured (fig. 27). Next, the end of the mold was constructed followed last by the top and bottom sides (fig. 28). The completed mold was carefully



Fig. 26. View of pattern mounted within divided wooden flask ready to receive sand (Courtesy of The Mariner's Museum)



Fig. 27. View of completed side mold sections (Courtesy of The Mariner's Museum)



Fig. 28. View of completed mold prior to disassembly (Courtesy of The Mariners' Museum)



Fig. 29. View of the disassembled mold's side sections showing the negative shape of the plastic pattern in the hardened sand (Courtesy of The Mariners' Museum)

disassembled in reverse sequence from its construction and the pattern was removed (fig. 29). Clear of the outer mold, the pattern was taken apart and the core molds removed (fig. 30). The parts were carefully reassembled and strapped together with metal banding (fig. 31). The finished mold was filled with liquid iron, and the following day the mold was broken open to reveal the casting (fig. 32).



Fig. 30. Overall view of the main mold core for the piston cylinder and cradle (Courtesy of The Mariners' Museum)



Fig. 31. View of the main core mold reinserted into one of the side mold sections receiving additional cleaning prior to reassembly of the rest of the mold (Courtesy of The Mariners' Museum)



Fig. 32. New steam engine and cradle being broken out of the sand mold (Courtesy of The Mariners' Museum)

5. FOUNDRY

For the project, castings were produced either through the use of a coke-burning cupola furnace for iron components or a gas-fed crucible furnace for bronze components at Buffalo State College. The operation of each furnace design required different skill sets, tools, and number of individuals to run the foundry. All casting work was conducted with the assistance of undergraduate and graduate students.

5.1 BRONZE CASTING

The crucible-type furnace used to cast the replica bronze Worthington pump components consisted of refractory-line metal cylinder and cover connected to a natural gas burner and an electric blower as seen in figure 33. Set at the center of the furnace was a clay graphite or Silicon Carbide

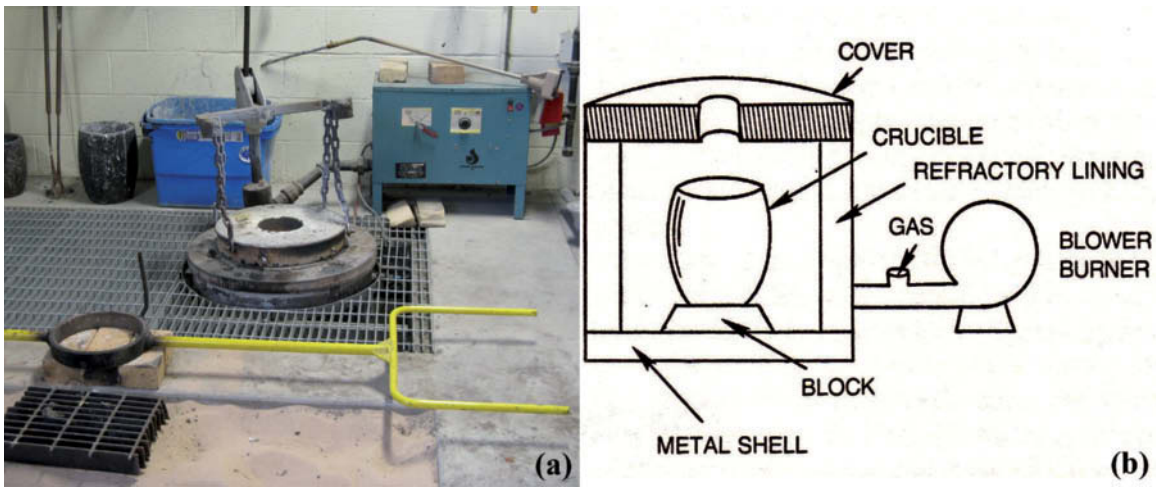


Fig. 33a. View of the bronze foundry with the furnace center image and shank in the foreground and crucible in background (Courtesy of The Mariners' Museum); 33b. Plan drawing of a furnace's components (Diagram adapted from Ammen 1979)

No. 40 crucible (holds approximately 120 lb. of metal). To operate the furnace, purchased bronze ingots and/or donated scrapped materials were placed into the crucible, the blower turned on, and gas ignited. Heat generated from combustion of the fuel and oxidizer liquefied the metal within the crucible. Once the bronze had fully melted, the lid on the furnace was removed and large tongs were used to lift the crucible out of the furnace and into a pouring shank. As soon as the crucible was transferred to the shank, impurities floating on the top of the metal were scooped out with a handled small flat steel plate called a skimmer. The shank with crucible were picked up and carried to a mold to be filled with metal. As bronze was poured, the skimmer was used to push any remaining impurities floating on the metal's surface to the back of the crucible to keep it from traveling into the mold and possibly ruining the casting. When the crucible was emptied, the shank was set down again and the tongs used to lift the crucible back into the furnace. The procedure was repeated if necessary. Due to the automated nature of the melting process, liquid metal could be produced in a relatively short period of time, and only a small foundry crew was required to operate the equipment and pour the molds.

5.2 IRON CASTING

To cast the iron components of pump a cupola furnace was used, which was basically a blast furnace in miniature as seen in figure 34b (Ammen 1979). The furnace was constructed of a refractory-lined cylinder that was open at the top and perforated by several holes at the bottom. To operate the cupola, the lower portion was filled with coke (coal baked in ovens at high temperature in a reducing atmosphere), which was ignited followed by the introduction of air from a blower connected to a wind

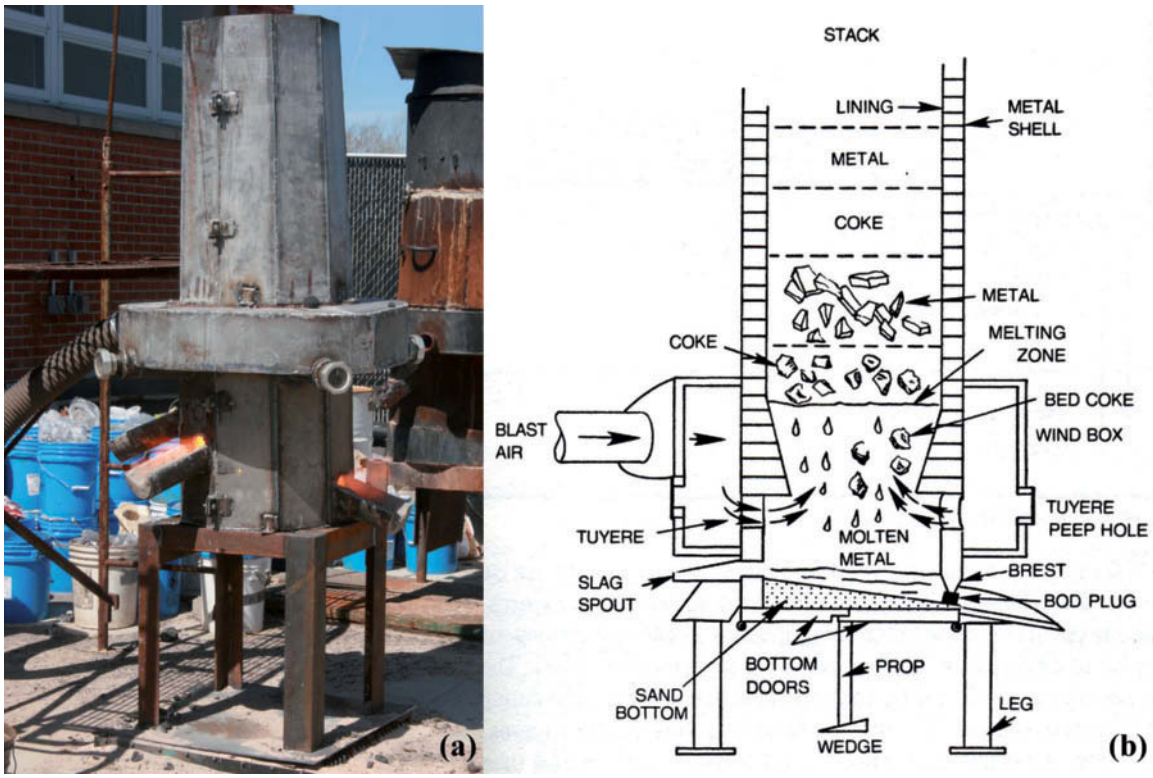


Fig 34a. View of the furnace at Buffalo State College during start-up prior to adding metal (Courtesy of The Mariners' Museum); 34b. Plan drawing of a cupola's components (Diagram adapted from Ammen 1979)

box that wrapped around the exterior of the furnace. Air reached the coke through a series of holes called tuyeres that connected the wind box to the interior of the furnace where combustion occurred and metal was liquefied at the melt zone near the top of the wind box. Once the furnace was started, alternating layers of coke and gray iron (broken up household radiators) were continuously inserted at the top of the stack in a process called charging. As the coke was consumed, the iron began to move down from the top of the furnace toward the melt zone. As the iron turned to liquid, it was collected at the very bottom of the furnace in an area called the well. When it was determined that the well was full of metal, a preheated refractory-lined ladle was placed at the front of the furnace and a clay plug called a bod (or bott) was knocked loose with a steel spike in a process called tapping allowing the liquid iron to flow out and fill the ladle. Once the furnace was drained of metal, another clay plug was inserted allowing the well to fill again. As with the previous casting method, the metal was skimmed to keep impurities from entering the mold cavities of the castings. Unlike the bronze foundry, the iron foundry needed a large group of workers to prepare the furnace for operation and to constantly maintain it while metal was being melted. Therefore, separate crews were required with one group running the furnace and the other to pour metal into molds. The cupola continuously produced metal until charges ceased to be added.

6. FINAL STEPS FOR THE REPLICATION PROJECT

At present, all casting has been completed for the pump and the project is in the finishing stage with the majority of components still receiving final machining work (fig. 35). This includes the boring of the piston and water plunger chambers, milling and planning of mating surfaces, and drilling bolt holes. Machining of the new pump's components is equally as challenging as their casting due to the custom nature of the work. Many of the pieces have to be independently modeled again in CAD software so that the data can be transferred to Computer- Numerical-Controlled (CNC) milling machines. Along with

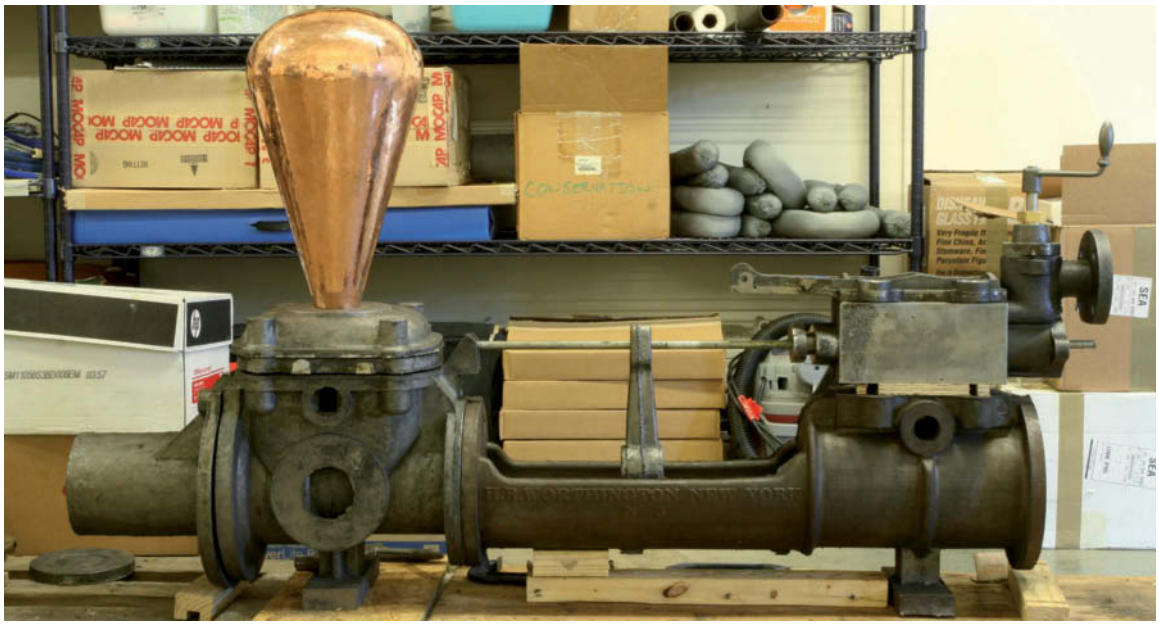


Fig. 35. View of the replica pump components loosely assembled to show their overall arrangement along with recently completed planished copper air-flask (Courtesy of The Mariners' Museum)

the machining of major assemblies, secondary components such as copper pipes and flange fixture that will be used to supply water and air/steam into the pump still need to be fabricated. The exact method to power the engine has not been completely decided. Although the use of live steam would be ideal, logistically it may not be the best option due primarily to safety concerns and portability. Steam boilers can be hazardous if not operated correctly or maintained properly. Therefore, the better option appears to be the use of compressed air to drive the piston. It is hoped that a functioning pump will be ready by January of 2014.

7. EDUCATION AND PUBLIC OUTREACH

Now that a working pump is on the verge of becoming a reality, discussion about uses for the replica from an education and outreach standpoint have started to develop and will readily fulfill the goals set out by the project.

Along with giving lectures and constructing a display about the project, educational programming will soon be developed directly around the object to teach about steam engines, 19th-century industrial technology, and help to build awareness about the challenges of marine archaeological conservation. By its nature, the replica is a perfect instrument to engage youth audiences. In our modern world of the internal combustion engine, which at this point looks like nothing more than a vibrating metal box, the mechanical movements of the steam engine's piston and valve rod will have the power to captivate children and adults alike.

Beyond the museum, the pump will be used in a public outreach capacity by taking it on road to steam shows, other museums, and historical sites. Bringing the replica to these venues will enable The Mariners' Museum to engage people that may otherwise have never come into contact with the institution, continuing its mission to tell the stories of USS *Monitor* and her crew. One possible outreach project currently in development that can readily incorporate the pump into its program is called the *Monitor* Trail. The overall project will involve museum staff traveling to all the sites that were involved in the life of the ironclad and provide public lectures about vessel and its role in shaping US naval history. What better way to tell the story of the ship's sinking than having one of its engines pumping water live in the background?

Along with the more traditional concepts of outreach, the replica has encouraged the museum staff to start thinking "out-of-the-box" in ways of using it to reach the public. For example, it has been mentioned that the pump could be used to run sprinklers that children could play in during the museum's outdoor summer concert series. There has also been discussion of using the Worthington to run a fountain during certain events, or possibly even be used to pump beer during the institution's annual craft beer festival.

8. CONCLUSION

Through the treatment and stabilization of *Monitor*'s Worthington pumps, the conservation staff at The Mariners' Museum gained a better understanding of how the artifacts were originally manufactured. As questions arose on how to relay the functionality of the now highly fragile objects to the broader public, a replication project became the perfect method to carry out this task. Through the project, partnerships have been built with public institutions and private industry revealing the potential of an endeavor such as this to attract donor and partnering support that may not have ordinarily occurred otherwise, support that will only continue to grow as the project move toward completion.

The ultimate reason for recovering and conserving artifacts from the wreck site of USS *Monitor* is to use the objects as mediums to tell the stories of the ship and her crew. The replica Worthington pump will not only help to advance this mission, but will also provide a unique opportunity to expose people to living history by making a direct connection to the past, which they can literally experience through sight, sound, and touch.

ACKNOWLEDGMENTS

The author gratefully acknowledges the support of Gerry Hanley, Gary Paden, Eric Nordgren, Dave Krop, Anna Holloway, Chris Leahy, and The Mariners' Museum. Special thanks must be given to Gary Wainwright, Chris Savage, and Donny Smith for their assistance without which the pump could not have been built. Thanks are also extended to Ken Payne, Elena Lourenco, Buffalo Iron, and the sculpture studio at the State University of New York College at Buffalo for their expertise, encouragement, and enthusiasm throughout the project. The author would like recognize the generous support of Gary McMurray, David Revere, and Master Machine and Tool Co. Inc. along with Frank Arsi, James Hamel, and Curtiss-Wright for their substantial technical and financial sponsorship enabling the replica to become reality. Acknowledgment must also be given to Mark P. Dishman, Ron Herzick, and the Virginia Institute of Marine Science through the College of William & Mary for the substantial donation of gray iron radiators used to cast the new pump. The author would also like to thank Robert Hoffman for helping to document the project through photography and videography.

NOTES

1. In 1845, Worthington partnered with William H. Baker to form the firm of Worthington and Baker; however, Baker died in 1853, and Worthington kept the name until 1862 when he changed it to his own.

2. As the various pump components were replicated, if possible, multiple copies were produced in case a mistake was made during the final machining process. For most of the small pieces, two copies were made of each.

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SOURCES OF MATERIALS

95-4-1 Everdur Silicon Bronze
Atlas Metal Sales
1900 W. 12th Ave
Denver, CO 80204
http://www.atlasmetal.com/

Alginate Super Deluxe
Darby Dental Supply
300 Jericho Quadrangle
Jericho, NY 11753
http://www.darbydental.com

Brush-On 35 Urethane Rubber
Smooth-On, Inc
2000 Saint John Street
Easton, PA 18042
http://www.smooth-on.com/

Dap Plaster of Paris
Ace Hardware Corporation
http://www.acehardware.com

Sculpture House Roma Plastilina Modeling Clay, medium
Dick Blick Art Materials
P.O. Box 1267
Galesburg, IL 61402-1267
http://www.dickblick.com/

Smooth-Cast 310 Urethane Plastic
Smooth-On, Inc
2000 Saint John Street
Easton, PA 18042
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